CHAPTER 10

Gears

It is difficult to generalize on intermittent motion gear systems because there are several basic types and they differ from each other in most characteristics. Some produce harsh impacts, some produce no impacts. Some characteristically produce only instantaneous dwell, others are used because they produce dwells of very long duration. Some are simple and cheap, others are complex and costly. All gear systems, however, require a continuous input rotation and, therefore, are probably never used with solenoid or fluid drivers.

Mutilated Gears

The easiest method of making an intermittent motion device from a pair of gears is to remove some of the teeth from the drive gear, as shown in Fig. 10-1. A gear with some of its teeth removed is sometimes called a mutilated gear, and if it is operated at high speeds or under high-load conditions, its name is well deserved! But if operated under a light load or at a reasonable speed, this is a very simple and versatile intermittent motion mechanism. Dwell and motion periods can be varied quite a bit depending upon the sizes of the two gears involved. The velocity ratio between input and output can easily be controlled by selection of the proper gear ratio. Nevertheless, this mechanism is an impact producer, as shown in Fig. 10–2. This is a simplified picture from that which would be obtained in most practical design situations where elasticity in the various parts of the system would result in multiple rather than single impacts.

The gear pair shown in Fig. 10–1 probably never would be found in practice. Some additional mechanism must be provided to hold the output gear during dwell periods to prevent the teeth of the two gears from "topping" as they re-engage. We will see some ways of accomplishing this in later illustrations.

Cycloidal Gearing

Another type of intermittent motion gearing is shown in Fig. 10–3. This is called a hypocycloidal gear train. A small "planet" gear runs around the inside of a fixed ring gear. A pin in the planet gear engages a slot in an output crank which rotates about the center of the ring gear, dwelling periodically as it rotates.

If the planet gear revolves around a fixed external or spur gear, as shown in Fig. 10–16, the system is called an epicycloidal gear train. The performance of these two types of cycloidal gear trains is similar. Anything we say about the hypocycloidal train is true or nearly true for the epicycloidal train, thus, we will discuss only the former.

The hypocycloidal gear train produces no impacts. It also produces only very short (theoretically only instantaneous) dwells. In these two characteristics, therefore, it differs significantly from the mutilated gear system considered earlier.

Figure 10–4 shows a schematic drawing of the gear train of Fig. 10–3. The dotted line represents the path taken by the drive pin as the planet gear moves around inside the ring gear. Since the diameter of the ring gear is an even multiple of the pitch

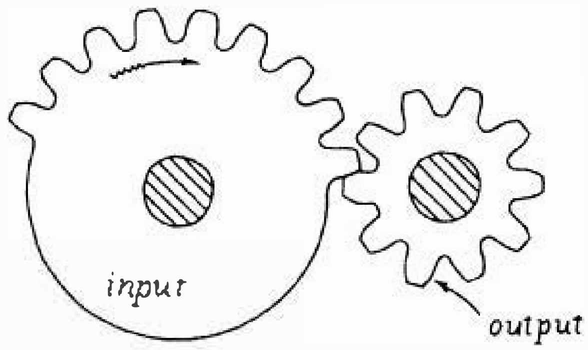


Fig. 10-1. Simple mutilated gear pair.

diameter of the planet gear (in the illustration, four to one) the drive pin will always follow the same path.

The instantaneous tangential velocity of the drive pin with respect to the center of the ring gear will vary as the rotational motion of the planet gear about its center is added to, and subtracted from, the rotational motion of the input arm about the center of the ring gear. (See Chapter 1 for the step-by-step procedure for determining the pin's tangential velocity.) The tangential velocity of the drive pin about the center of the system will be at a minimum in the position shown in Fig. 10-4 (and at the other three "corners" of the "square" being described by the pin). With the pin mounted about halfway between the center and pitch diameter of the planet gear, as shown in Fig. 10-4, the tangential velocity of the pin will never reach zero. If the pin were mounted on the pitch line of the planet gear, however, as shown in Fig. 10-5, it will describe a slightly different path, as shown, and there will be four times during each revolution of the input when

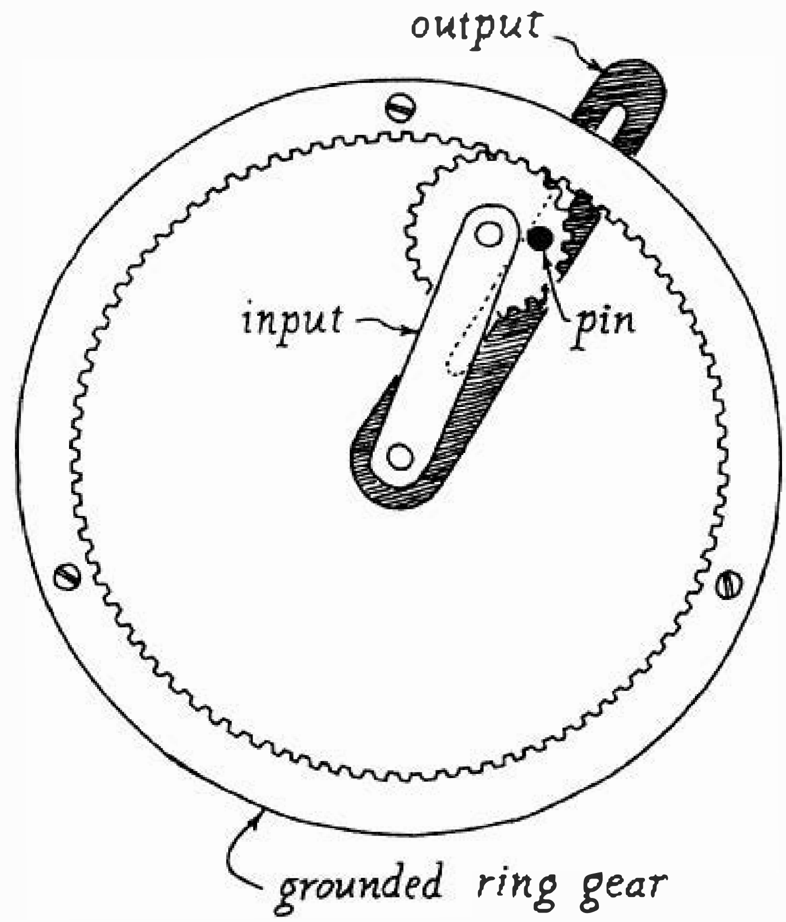


Fig. 10-3. Hypocycloidal gear train with a four-to-one ratio. The drive pin is located about halfway between the center and the pitch line of the planet gear.

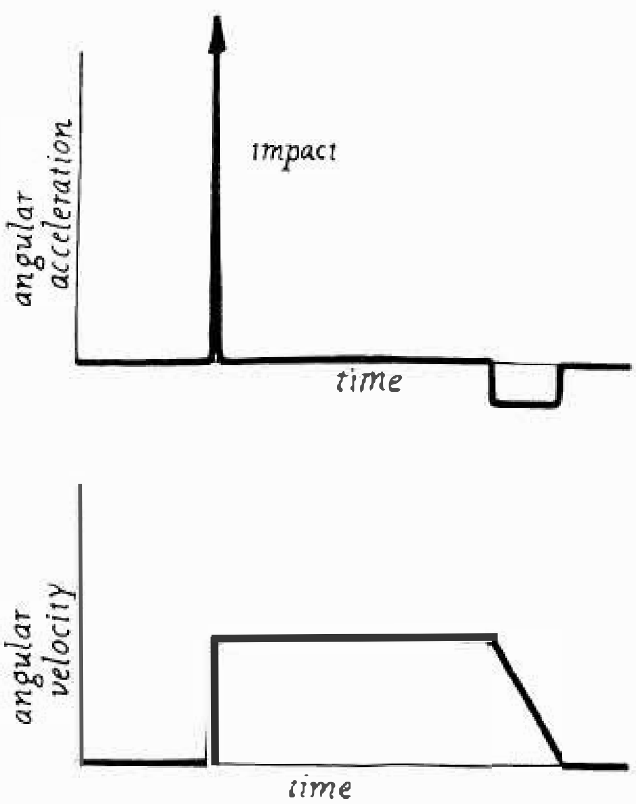


Fig. 10-2. Motion curves for the mutilated gears of Fig. 10-1.

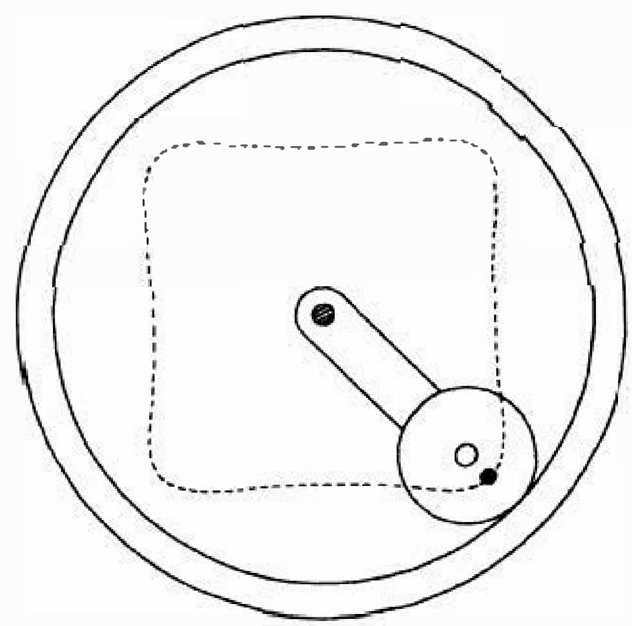


Fig. 10-4. Schematic illustration of the hypocycloidal gear train of Fig. 10-3.

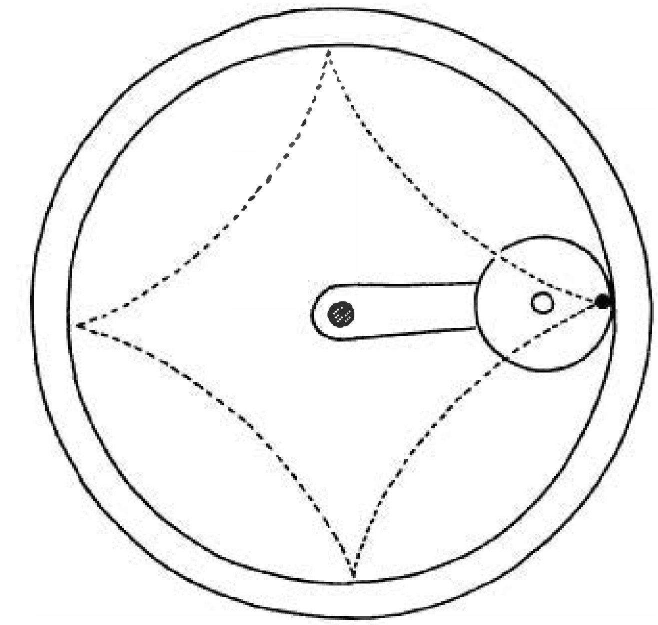


Fig. 10-5. Schematic representation of a four-to-one hypocycloidal gear train with the drive pin located on the pitch line of the planet and ring gears.

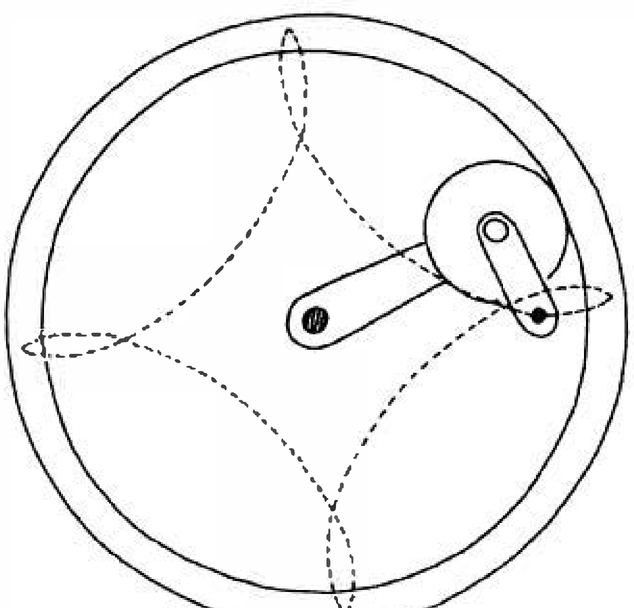


Fig. 10-6. Schematic representation of a four-to-one hypocycloidal gear train with the drive pin mounted beyond the pitch line of the planet gear.

the tangential velocity of the pin will be exactly zero. Theoretically, these are only instantaneous points but with backlash between planet gear and ring gear and/or backlash between the drive pin and the slot in the output crank, this instantaneous dwell period can be extended slightly. Of course, if it is extended too much by the introduction of backlash, impact can result when motion recommences.

If the drive pin is mounted on a small arm which is fixed to the planet gear so that the pin is operating on a radius that exceeds the pitch radius of the planet gear, then the pin will describe the motion path shown in Fig. 10-6. Under these conditions the tangential velocity of the pin around the center of the system actually reverses momentarily, four times during each drive cycle, as shown by the four cusps on the dotted-line path of Fig. 10-6.

Again, if backlash is purposely introduced into the system, perhaps between the pin and the slot in the output crank, then the entire period described by the cusps in the pin path can be converted to dwell in the output. Figure 10-7 shows the motion curves for the output crank of a hypocycloidal system (for 180 degrees of rotation of the input crank) when the drive pin is located on the pitch diameter of the planet gear. As can be seen from the velocity curve the dwells are only instantaneous, as explained above.

Cycloidal gear trains can be used alone to produce intermittent motion if short dwell periods are acceptable. They are frequently used, however, with other intermittent motion mechanisms such as Genevas or ratchets: in this case, the cycloidal gear is included to reduce impact velocities in the other mechanisms. With a Geneva, for example, the cycloidal gear train would be used to reduce the velocity of the Geneva drive pin at the moment the

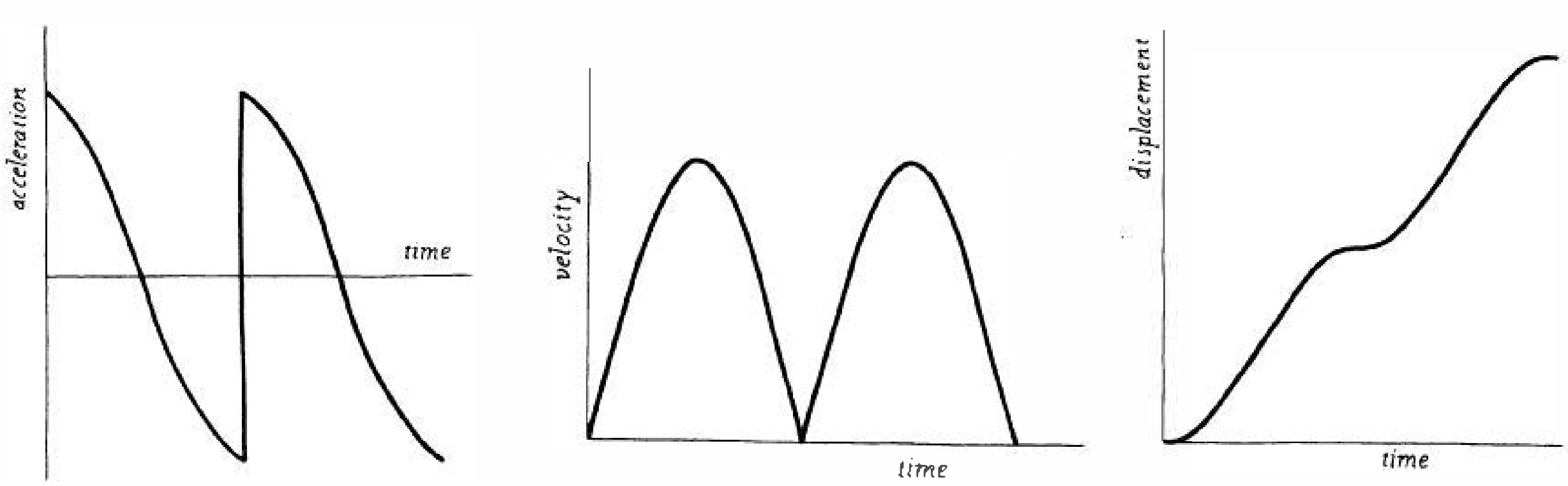
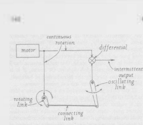


Fig. 10-7. Motion curves for a hypocycloidal gear train in which the pin is mounted on the pitch line, as in Fig. 10-5. These three curves represent the motion of the output crank of the gear train (shown in Fig. 10-3) for 180 degrees of rotation of the input crank.



Photograph courtesy of the Fairchild Hiller Corp.

Fig. 10–8. (*Top*) Schematic describing a system where a differential gear can be used with a motor and a four-bar linkage to produce intermittent motion. The differential is used to add a continuous motion to an oscillatory motion. (Also see Fig. 10–9). (*Bottom*) Two typical bevel gear differentials.

pin enters the slot of the Geneva wheel. We saw an example of this in Chapter 9.

One advantage of cycloidal systems, of course, is t[illegible] of impact. A big disadvantage [illegible] the fact that only momentary dwells can be obtained. These are not very popula[illegible]ent mot[illegible] devices, perhaps because of the short dwell or because they involve sliding parts, or simply due to the fact that man[illegible]e not familiar [illegible]ese [illegible]

[illegible]

Differe[illegible] gears are commonly used to add or subtract one shaft rotat[illegible] to or from another. Strictly speaking, they are also cycloidal gears, but we wi[illegible]hem separately because they [illegible] can utilize) more than one input [illegible] can produce [illegible]ariety of outputs. Taken alone different[illegible] are incapable of producing intermittent motion. With the proper inputs, however, they can produce intermittent mot[illegible] without impact. In Fig. 10–8, for example, we see (top) a schematic of a s[illegible] in [illegible] a motor continuously [illegible] one side of a [illegible]erent[illegible], such as the bevel[illegible] differe[illegible] the photograph, and also drives the [illegible] of a four-bar linkage. The oscillatory output of the four-bar linkage [illegible] to the other [illegible] of the differential, whe[illegible] it periodically adds to and subtracts from the steady input from the motor. The result of [illegible] these continuous and [illegible]ry inputs [illegible] intermitt[illegible] output motion with momentary dwells, as shown by the velocity curves of Fig. 10–9. Again, dwell is (theoretically) only instantaneous, but with backlash, etc., in this system it will probably be longer than [illegible]aneous in any practi[illegible] situation. If [illegible] number 2 [illegible] different[illegible] system were provi[illegible]ded a reversible elect[illegible] motor drive of its own, the dwell period could be anything the designer wanted to make [illegible] advantage of the differential approach. The differential in this case is

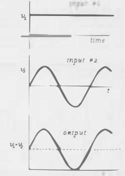
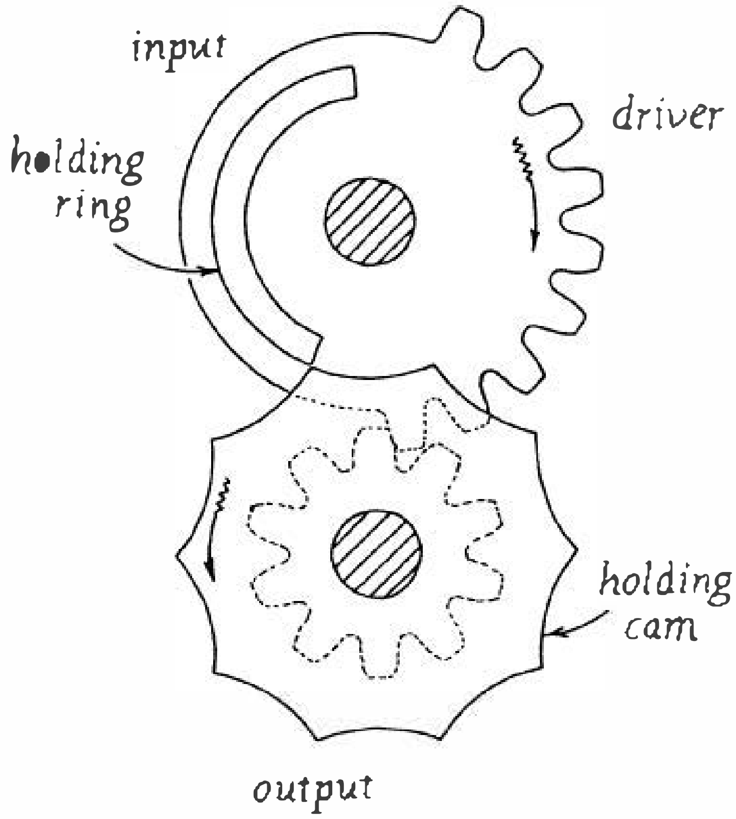


Fig. 10–9. Curves showing the input and output velociti[illegible] of the differential system shown schematically in Fig. 10–8.

really replacing one or more clutch-brake combinations.

The designer should always be sure that his differential is designed to dissipate the amount of energy that it will have to absorb if it is subtracting the total input received from one electric motor, from the total received from another. When the output of the differential is zero, all input work must be dissipated within the differential itself. This "circulating horsepower" as it is called by gear designers, can produce heat and wear even when the system is apparently doing no work.



Drawing courtesy of MACHINE DESIGN Magazine; Dec. 23, 1965; p. 121 ff

Fig. 10-10. Mutilated gear system with locking or holding ring and holding cam.

Miscellaneous Gear Systems

Mutilated, cycloidal, and differential gears are the main types used to produce intermittent motion. Special situations demand special solutions, however, and clever designers have thought up other unusual ways to use gears to produce stepping outputs. We will take a look at some of these after we have considered several versions of the traditional methods.

A mutilated gear system with locking or holding ring and holding cam to lock the output gear during dwell periods is shown in Fig. 10-10. Some such holding arrangement is essential in the mutilated gear system to eliminate topping of teeth as the gears engage. Topping, of course, could cause impact, jamming, complete destruction of the teeth, etc., and must be prevented.

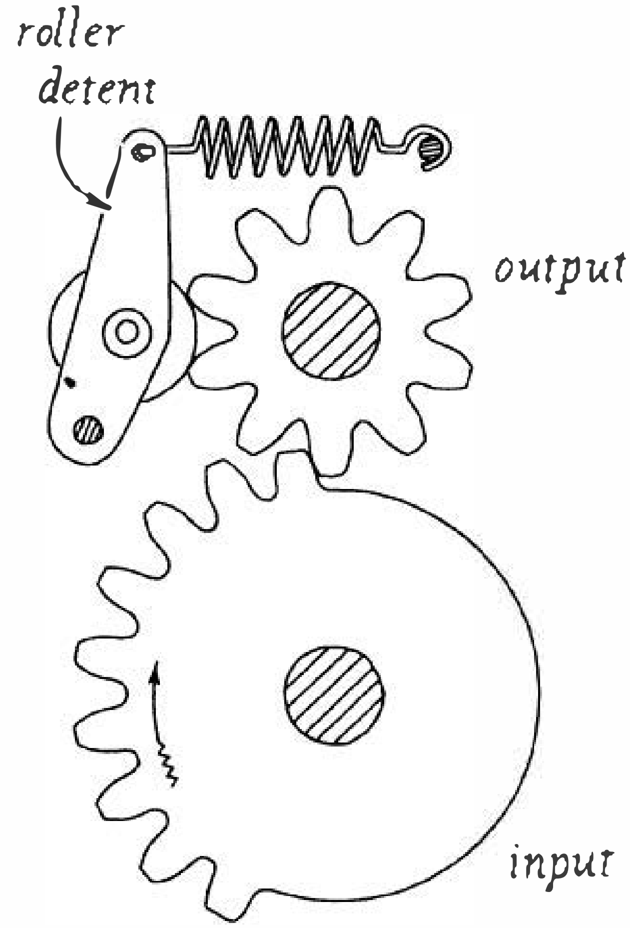
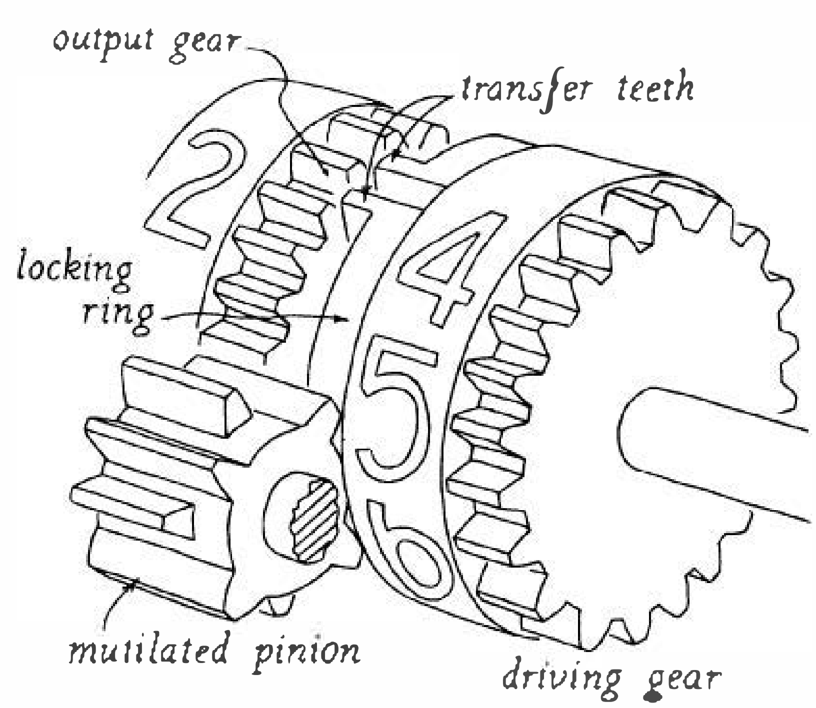


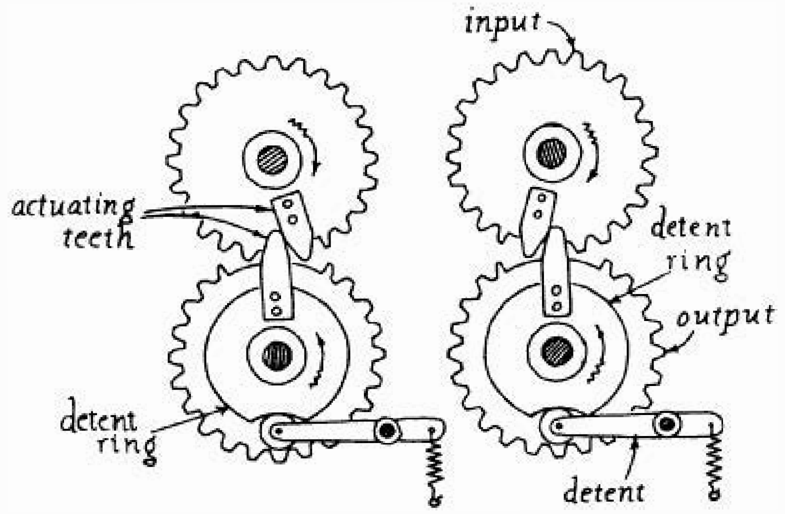
Fig. 10-11. Mutilated gear with roller detent.

Another method of holding output during dwell periods, perhaps not quite as common a method as that shown in Fig. 10-10, is the mutilated gear with roller detent (Fig. 10-11), used in place of a locking ring.



Drawing courtesy of the Veeder-Root Company

Fig. 10-12. Mutilated pinion transfer mechanism used in a mechanical counter.



Drawing courtesy of PRODUCT ENGINEERING Magazine: Dec. 20, 1965: pp. 86-93

Fig. 10-13. Mutilated gear arrangement with large actuating teeth.

Figure 10-12 shows a mutilated pinion transfer mechanism used in a mechanical counter. The alternate teeth on the pinion are extended full length to engage a locking ring on the drive wheel (the right-hand number wheel). The effect is the same as that obtained by the holding ring and holding cam surfaces of Fig. 10-10, however, the embodiment is different.

Some teeth are also missing from the output gear of the mutilated gear arrangement shown in Figure 10-13, but here large actuating teeth are provided to initiate motion. Note that the output is also locked by a roller detent rather than by a locking ring. The ratio of motion to dwell differs from that obtained with a conventional mutilated gear.

There will be two dwell periods and two motion periods for each revolution of the input shaft in the mutilated gear system, as shown in Fig. 10-14. One of these motion periods will be twice the velocity of

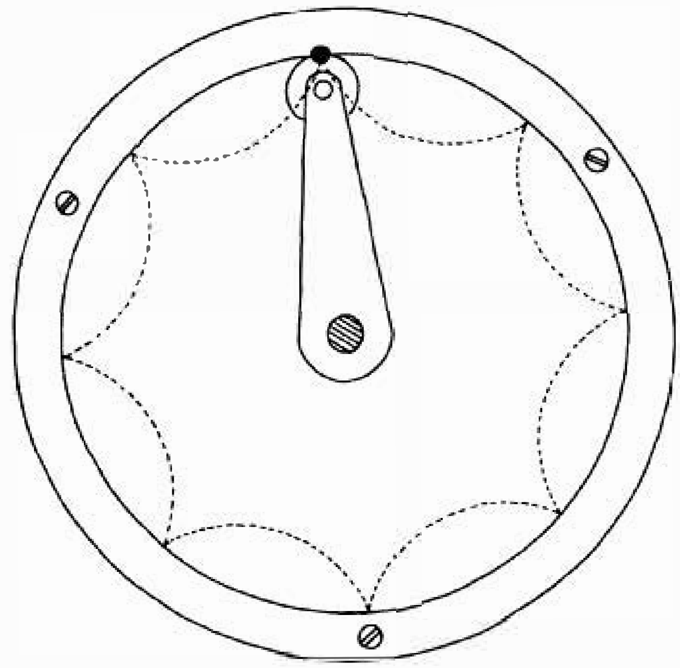


Fig. 10-15. Hypocycloidal gear train with an eight-to-one ratio.

the other; as first the right-hand and then the left-hand mutilated gear pairs will drive the output.

This hypocycloidal gear train system (schematic, Fig. 10-15) with an eight-to-one ratio and the drive pin located on the pitch line of the two gears, will produce eight instantaneous dwells per revolution of the input arm. Compare this system with that in Fig. 10-5, which has a four-to-one ratio.

Epicycloidal trains produce momentary dwells similar to those produced by hypocycloidal gear trains. The system shown in Fig. 10-16, an epicycloidal gear train with a one-to-one ratio, would produce one dwell per revolution of the input crank. As with hypocycloidal gears, the sun gear diameter must be an even multiple of the planet gear diameter

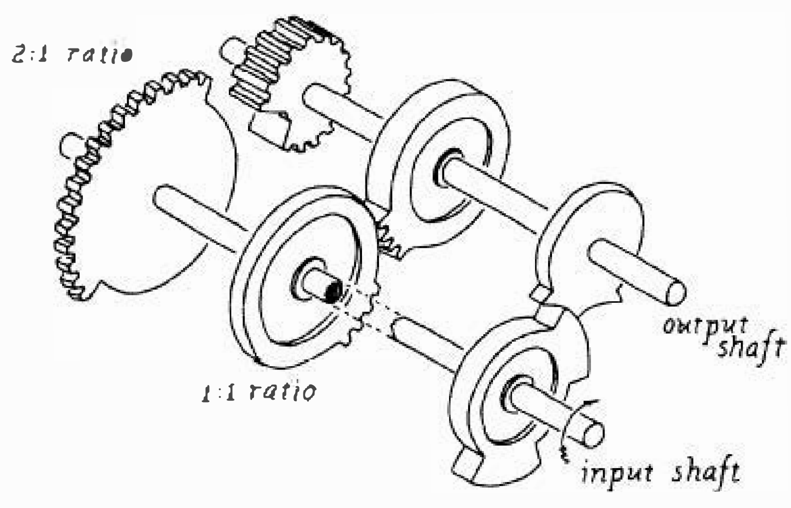
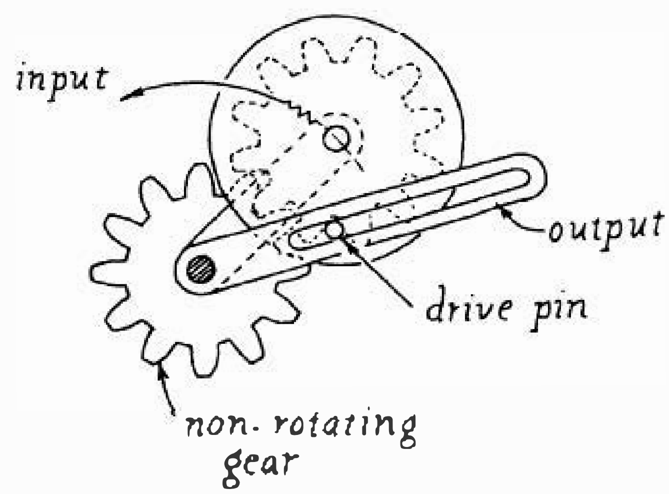


Fig. 10-14. Mutilated gear system with output motion at two different speeds.



Drawing courtesy of MACHINE DESIGN Magazine: Dec. 23, 1965: p. 121 ff

Fig. 10-16. Epicycloidal gear train with a one-to-one ratio.

if the dwell is to occur at the same point in each rotation.

The schematic shown in Fig. 10–17 is of a two-to-one ratio epicycloidal gear train with the drive pin located on the pitch radius of the planet gear. Such a system would produce two dwells per input revolution as shown.

Figure 10–18 shows another design in which an oscillatory motion is added to, and subtracted from, a continuous motion. This is a planetary gear train in which the motion of a segmented planet gear is modified by a cam.

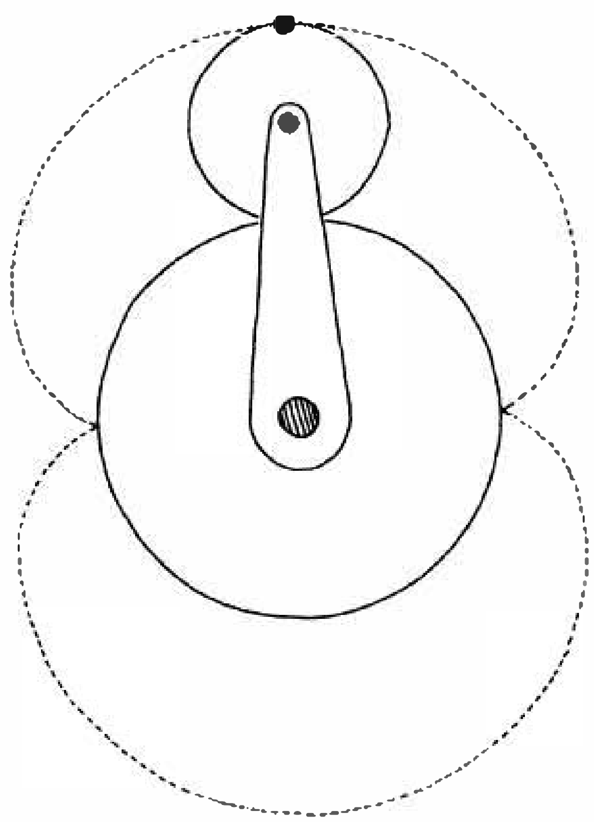
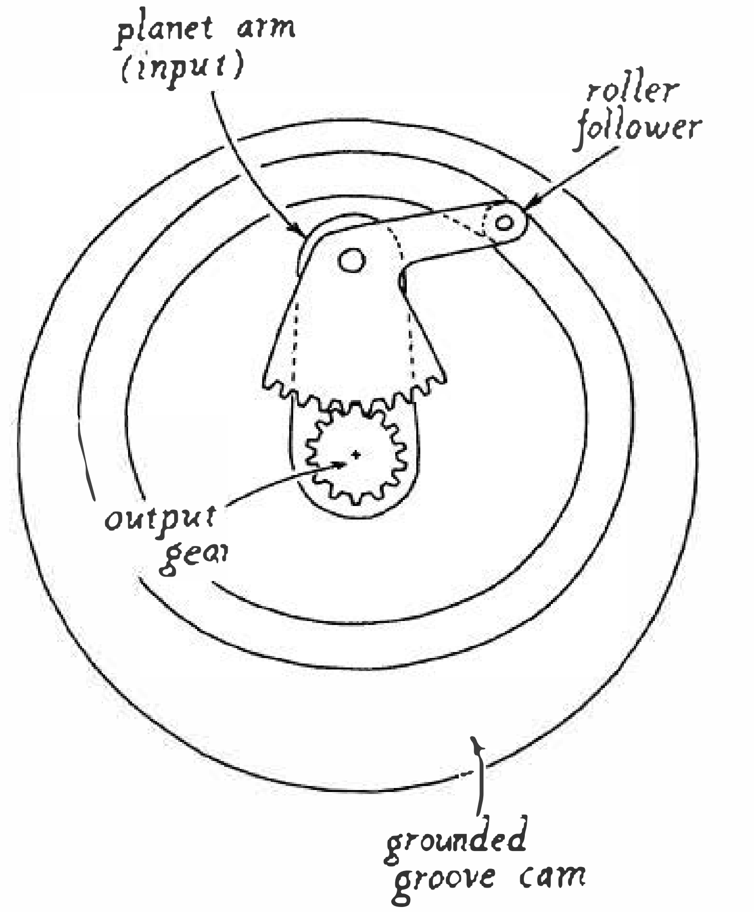


Fig. 10–17. Two-to-one ratio epicycloidal gear train with drive pin located on the pitch radius of the planet gear.

Noncircular gears modify the motion of the planet gear in the planetary gear mechanism shown in Fig. 10–19, to produce intermittent output from a single continuous input. The ratio of motion to dwell time can be adjusted by varying the shapes and diameters of the gears. Output motion is zero in a planetary gear assembly when the inputs cancel each other. With these noncircular gears, one input cancels the other periodically during each cycle. This occurs when the radius of gear (1) equals that of gear (2); and, at the same time, the radius of gear (3) equals that of gear (4). (See also detailed drawing in Fig. 10–19.)

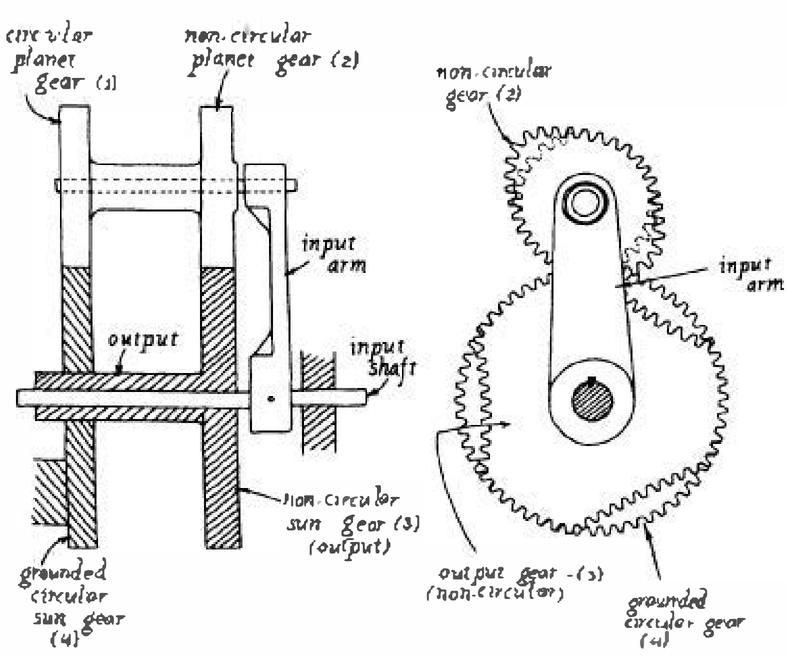
As with other cycloidal gear systems, the length



Drawing courtesy of PRODUCT ENGINEERING Magazine; Jan. 4, 1960; pp. 88, 89

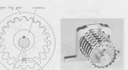
Fig. 10–18. Planetary gear train. Segmented planet gear motion is modified by a cam.

of dwell of this simple hypocycloidal gear mechanism (*left*, Fig. 10–20) used in a small counter (*right*), will depend upon the backlash between the grounded pin and the slot in the input gear.



Drawing courtesy of PRODUCT ENGINEERING Magazine; Nov. 27, 1971

Fig. 10–19. (*Left*) Planetary gear mechanism with non-circular gears. (*Right*) Details.



Photograph courtesy of the Veeder-Root Company
Drawing courtesy of MACHINE DESIGN Magazine; Dec. 88, 1955; p. 181 ff

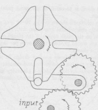
Fig. 10-20. (*Left*) Simple hypocycloidal gear system used in a small countermechanism. (*Right*) Small counter mechanism.

In this design, Fig 10-21, the cycloidal gearing is used to reduce the velocity of the [illegible] as it enters the drive slots [illegible] an internal Geneva wheel. [illegible] converts the short dwell of the ~~cycloidal train~~ to the relatively long dwell of a Geneva mechanism.

In a modified motion Geneva system (Fig. 10-22) [illegible] gears are used to modify the motion of a Geneva drive pin, the goal [illegible] being to reduce the impact velocity of the pin as it enters th[illegible]

Systems such as the one shown in Fig 10-23 could be used with motors, clutches, brakes, linkages and other [illegible] produce a wide variety of i[illegible]mittent motions for heavy-duty applications.

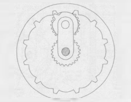
Figure 10-24 [illegible] a copy of the patent drawing for a single-input differential gear assembly. In this clever,



Drawing courtesy of PRODUCT ENGINEERING M[illegible] 1964 pp 67 68

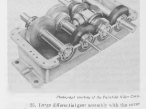
[illegible]

nonimpacting mechanism developed at the National [illegible] Company, a single [illegible] to a differential system produces [illegible] intermittent output. The [illegible] is through shaft *12* and the ring gear *38*, [illegible] fixed (grounded). The output of the system is on shaft *18*. Perhaps the system can be best understood by reference to the explanatory details in Fig. 10-25. The [illegible] at the top of this [illegible] produce rotat[illegible] the output shaft whenever the [illegible] shaft [illegible] rotated [illegible] would be on a



Drawing Courtesy of PRODUCT ENGINEERING [illegible] 1964 pp 109, 110

Fig 10-21. Cycloidal gear Geneva system.



Photograph courtesy of the Fairchild Hiller Corp.

[illegible]23. Large differential gear assembly with the cover removed.

one-to-one basis. If the bevel gears in the bottom sketch are rotated, they will drive the output shaft through the crank and yoke mechanism, producing oscillatory output. Now referring back to Fig. 10–24; as the input shaft (12), is rotated, it in turn rotates yoke *16*. This would produce pure rotation in output shaft *18* if it were not for the fact that the bevel gears *40* and *44*, are forced to rotate by the action of the fixed ring gear *38*, as the yoke *16*, rotates. As a result, oscillatory motion is added to and subtracted from continuous motion (as was seen in Fig. 10–9) to produce an intermittent output with (theoretically) instantaneous dwells.

Here, in Fig. 10–26, is another version of the differential mechanism patent shown in Fig. 10–24. Shaft *48* and shaft *30* are continuously driven by separate

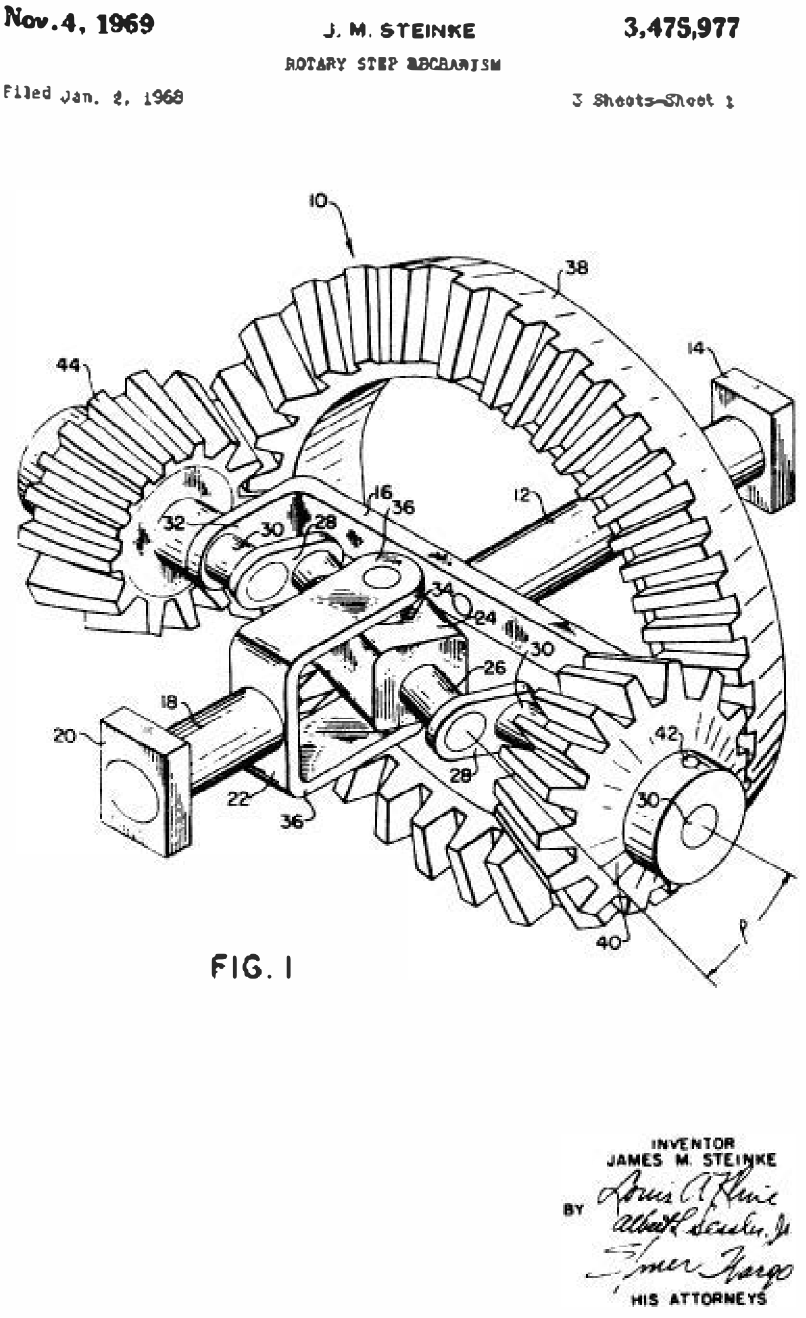


Fig. 10-24. Rotary step mechanism, patent sheet 1. (U.S. Patent 3,475,977; J. M. Steinke)

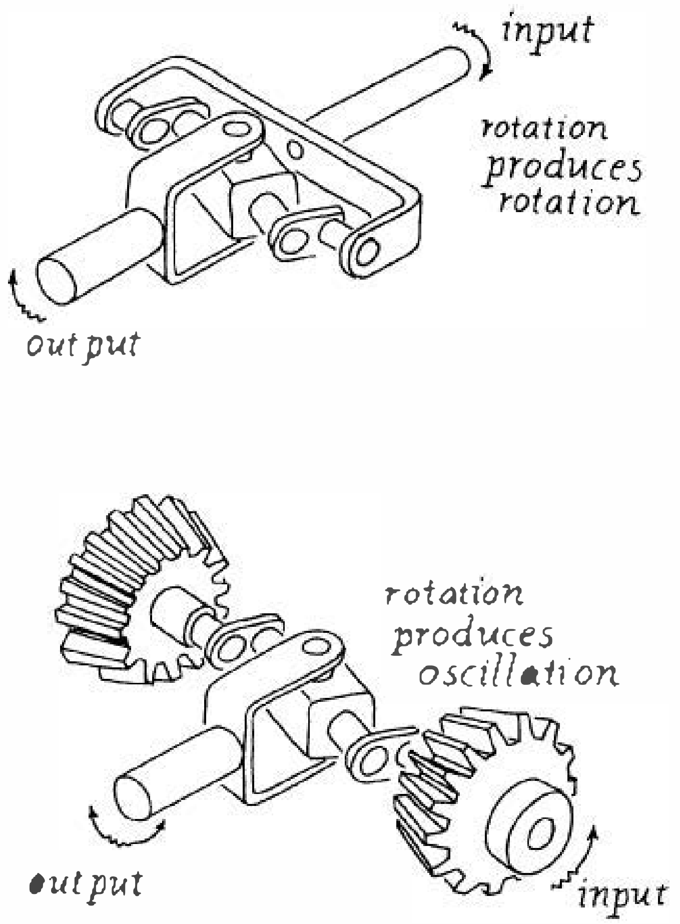


Fig. 10–25. Some analysis of the rotary step mechanism in Fig. 10–24.

motors. Shaft *48*, driven alone, would produce continuous rotation in output block *56*; shaft *30* alone would produce oscillatory motion in the output. If both inputs are introduced at the same time, therefore, the output motion will be intermittent. The inventor claims that the system can be used to produce hundreds of dwells in the output for each revolution of output shaft *54*. Although the dwells are theoretically only instantaneous in this mechanism, the inventor also states that velocity in the output is low enough, for a long enough period at each dwell point, to make the actual dwell finite and useful.

A rack-and-gear system used on a heavy-duty indexing table is shown in Fig. 10-27. The input rotates continuously. In sketch (A), at the top of the illustration, however, the output gear is held stationary by rack gear #1. The drive gear then merely rolls along the surface of the output gear without producing any output motion. When it is desired to index the table, rack #1 is extracted from the output gear and, as shown in (B) lower sketch, rack #2 is moved to the right to engage the left-hand side of the drive gear. The drive gear now rolls along rack #2 and drives the output gear. The two gear racks could be controlled by a cam on the same input

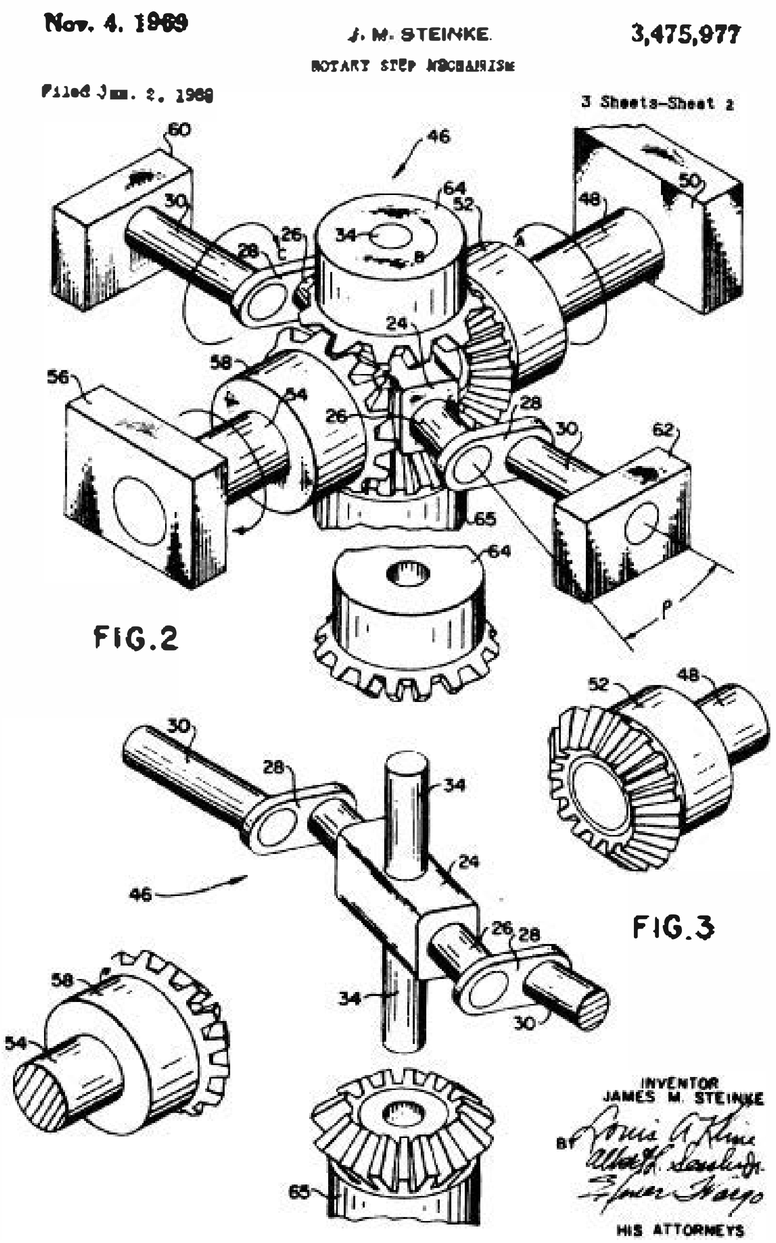


Fig. 10-26. Rotary step mechanism, patent sheet 2. (U.S. Patent 3,475,977; J. M. Steinke.)

shaft that moves the drive gear, to produce automatic indexing; or they could be driven separately to put the dwell period under the manual control of an operator.

In another interesting gear mechanism from National Cash Register (Fig. 10-28), an oscillatory motion is added to and subtracted from a continuous motion to produce intermittent motion output. Figure 10-29 illustrates this system with some detailed drawings. If the segmented gear shown in the mechanism at the top of the illustration would oscillate, it would produce oscillation in the output gear. If the ring in the center sketch of Fig. 10-29 is rotated, it will rotate the output gear on a one-to-one basis, thanks to the gear segment that is part of the ring. Thus, if a segmented gear is fastened to a ring, but is forced to oscillate as the ring rotates, it will produce intermittent motion in the output gear, as shown in the sketch at the bottom. In the mechanism of Fig. 10-28, the segmented gear is fastened to a pair of cam followers that force it to oscillate as the ring in which it is mounted is rotated around the output gear.

Earlier it was said that gears are always used in systems which have a continuously rotating input. However, every rule has its exception and Fig. 10-30 shows one, for the driver in this case is operated by a solenoid. The cam surfaces on the driver index a mutilated pinion identical to that in Fig. 10-12. The mutilated pinion, in turn, drives the output gear.

The three-gear system in Fig. 10-31 has to be seen to be believed. The input crank rotates through 360 degrees, carrying with it the left-hand gear which is rigidly fastened to the input crank. The output gear will either hesitate periodically, dwell instan-

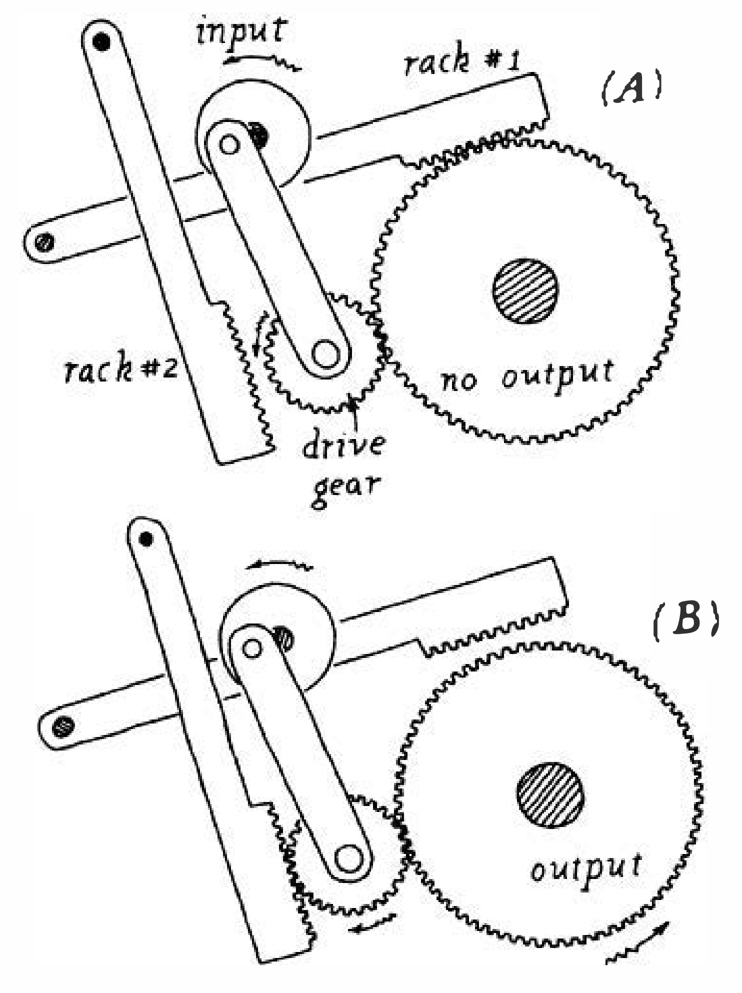


Fig. 10-27. Rack and gear system used on a heavy-duty indexing table. (Drawing made from information supplied by Gilman Engineering and Manufacturing Co.)

taneously periodically, or reverse motion during each revolution of the input crank depending upon the gear ratios involved.

The large input "gear" in the system shown in Fig. 10-32 has teeth (pins) which can be set in one of two positions. In the outer position they will

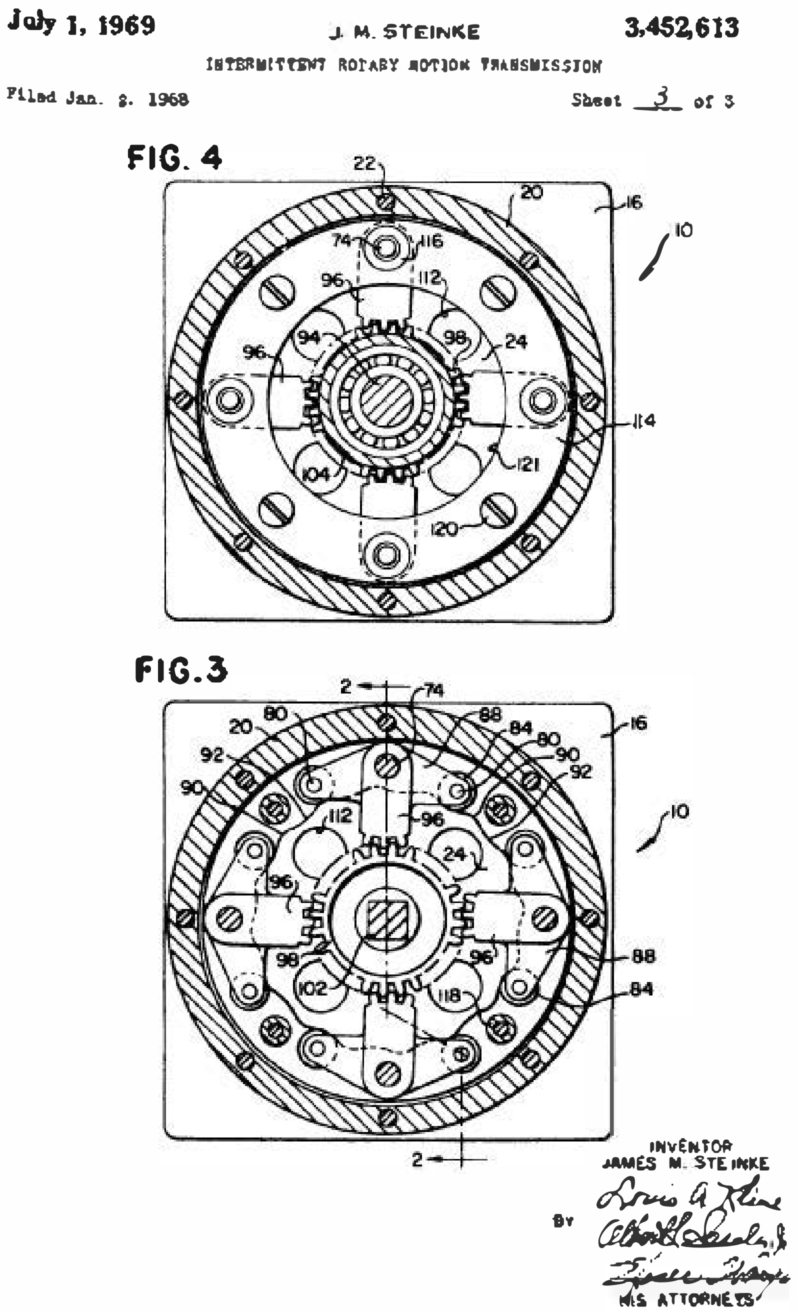


Fig. 10-28. Intermittent rotary motion transmission. (U.S. Patent 3,452,613; J. M. Steinke.)

engage the teeth of a small star wheel as the input disc rotates. If the pins are moved toward the center of the input disc they will not engage the star wheel. As a result, the output of the star wheel can be programmed to some extent. The model I saw had a 6-inch diameter input disc with 40 pins and a 1-inch diameter output wheel. Note that a detent roller is used to hold the output during dwell periods.

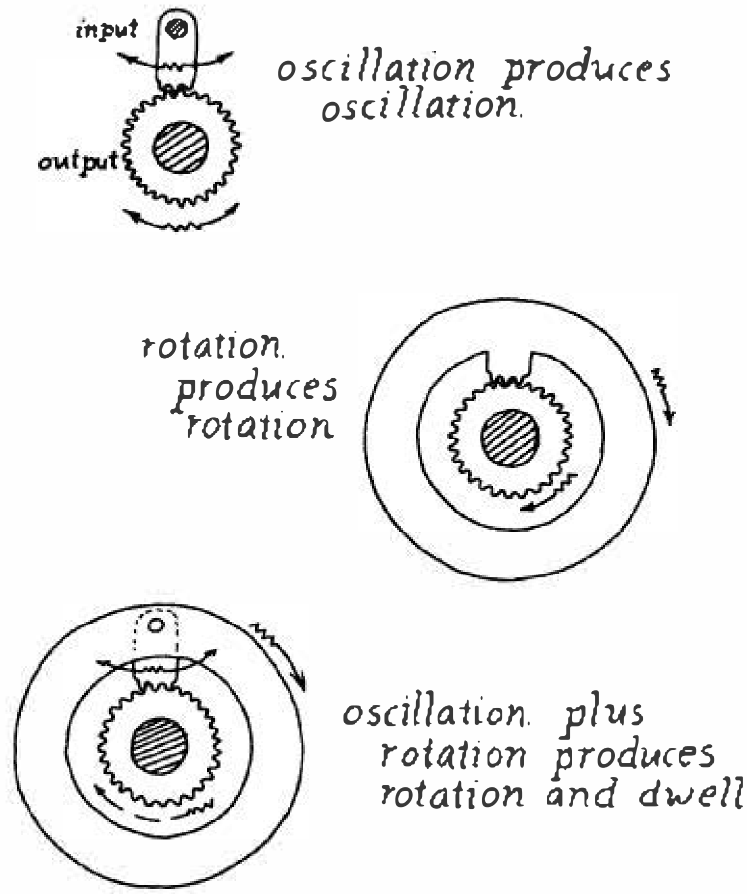


Fig. 10-29. Analysis and details of the gear mechanism of Fig. 10-28.

Anatomy of a Gear

There is a very great deal more to a gear than meets the unpracticed eye. The information below, on various parts of a gear, and shown in Fig. 10-33,

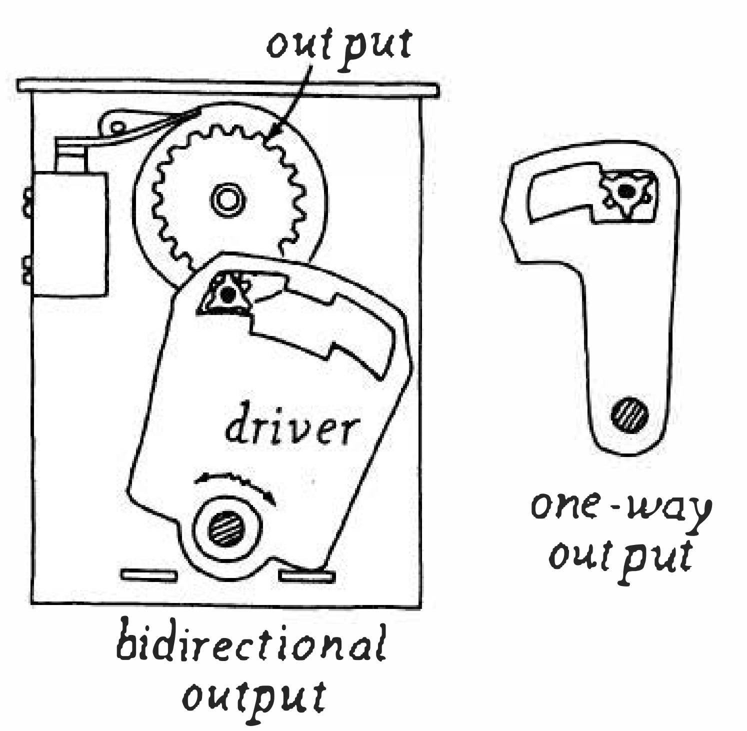
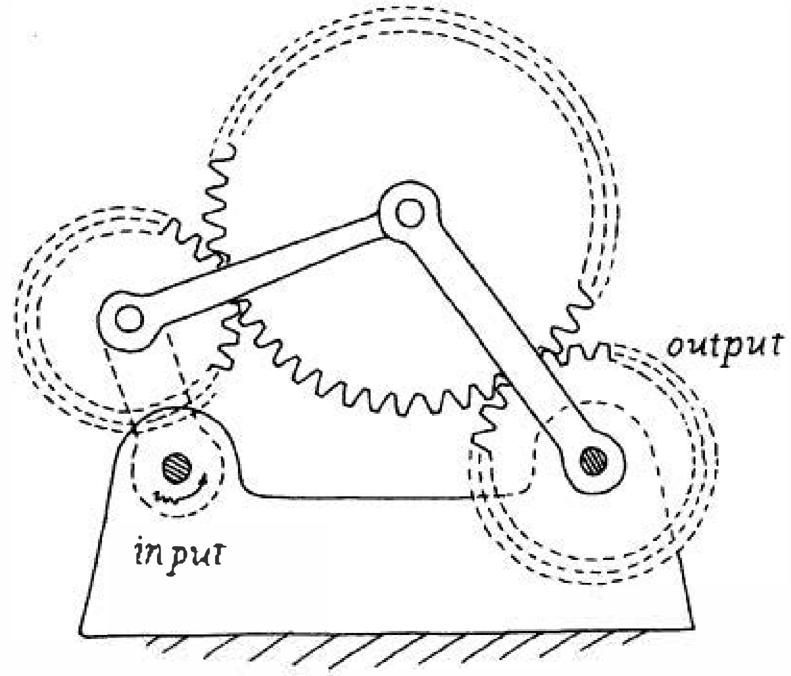


Fig. 10-30. Continuously rotating gear system with solenoid operated driver. (U.S. Patent 3,390,834; H. L. Seiden.)



Drawing courtesy of PRODUCT ENGINEERING Magazine; June 8, 1964; pp. 67, 68

Fig. 10–31. Three-gear system.

does not even come close to scratching the surface, but may, at least, show you that gears are not as obvious as they look. And these are "plain" gears; not bevel, worm, helical, herringbone, spiral, skew, hypoid, miter, hypocycloidal, or intermittent gears!

A. Drive gear, input—running at constant velocity; *B*. Driven gear, output—should

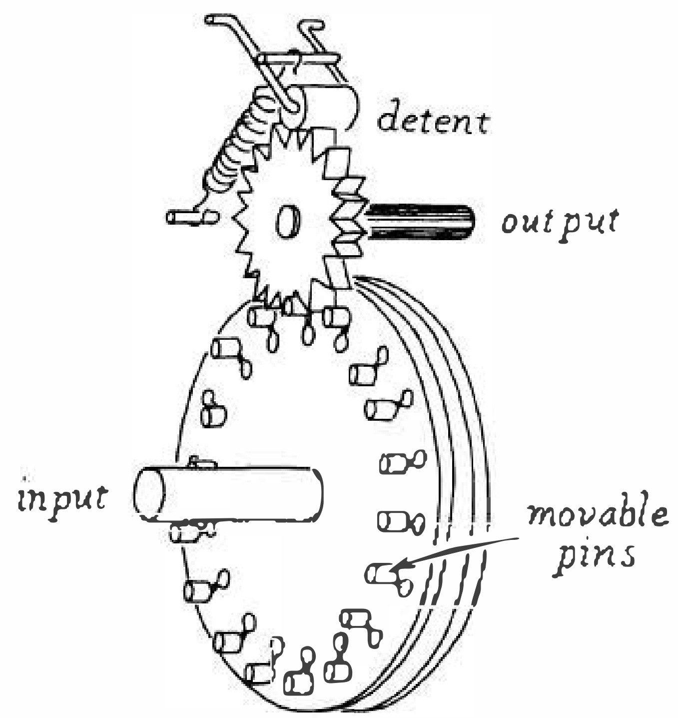


Fig. 10–32. Programmable "gear."

also run at constant velocity; *C*. Single gear tooth—could be (and is) a variety of shapes. But once its shape is chosen, the shape of the mating gear tooth is determined by the requirement that the output gear "should also run at constant velocity." Of all the shapes chosen for gear teeth the most popular is the involute curve because it is relatively easy to generate; it will produce constant velocity in the output gear (if both input

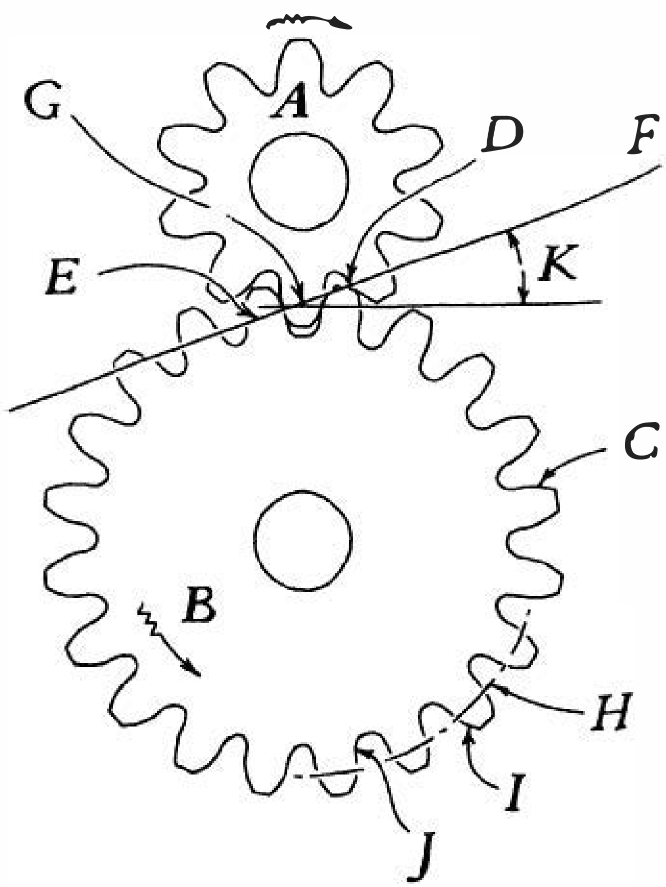


Fig. 10–33. Anatomy of a gear.

and output teeth are involutes); and it provides for interchangeability of gears, since input and output teeth are identical. Sometimes, the involute is modified slightly, however, to avoid undercutting of the teeth (for example on a small pinion); *D*. The point at which the teeth of the two gears first make contact as they turn; *E*. The point at which the teeth last make contact; *F*. Line of action of the gear teeth—joins *D* and *E*; passes through *G*. All contact between the gears must be (and nearly is) along this line if a constant "lever rat[illegible]" is to be [illegible] between [illegible] and [illegible] gears at all times. [illegible] line [illegible] also tangent to the base [illegible] of the [illegible]volute curves of the teeth on both gears, *G*. Pitch point—intersection of the line of action and of the line joining the centers of the two gears, *H*. Pitch [illegible] might be considered the "centerline" of the teeth on both gears. Passes through the pitch point and is [illegible] by it). *I*. Addendum—that portion of the gear tooth that is outside the pitch circle; *J*. Dedendum—that porti[illegible] of the tooth that is below the pitch circle. Usually the dedendum is made larger than the addendum to provide clearance for the mat[illegible] teeth. *K*. Pressure angle—angle between line of action and the [illegible] tangent to the pitch circles of the two gears and passing through the pitch point. A small pressure angle would be mor[illegible] than a large, because conventional gears cramp each other for that portion of tooth contact that lies in front of the line joining their centers, and a smaller pressure angle results in less cramping. But a small angle also results in undercutting of the teeth and a subsequent loss of strength. The most common pressure angles are 14½ degrees and 20 degrees.

[illegible]

Several of the gear systems we have seen [illegible] chapter were ~~designed for~~ high-speed business ma-

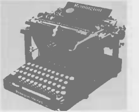


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Fig. 10-34. [illegible] ratche[illegible] the platen and machine escapements to index the carriage.

[illegible] Int[illegible]ttent motion [illegible] and systems of all types have been, and are being used, in such machines, of course. In fact, this is probably the area [illegible] intermittent motion development work is being done at the present [illegible] how to move paper, cards, printing heads, etc., fast [illegible] to keep up with [illegible] electronics. It is quite a challenge. The photograph in Fig. 10-34 shows a 1907 Remington typewriter that uses manually powered ratchets to index the platen and machine escapements to index the carriage.